Smart Museum of Everyday Life History in Petrozavodsk State University: Software Design and Implementation of the Semantic Layer

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***Abstract*—Since 2016 a smart museum of everyday life history has been developed within the History Museum of Petrozavodsk State University. This R&D project aims at solutions to the two important problems for creating a digital service-oriented environment for museum visitors and personnel: 1) offering personal recommendations on the museum collection with the use of semantic ranking methods and in context of the user and exhibition, 2) collaborative addition of information sources and their semantic annotation within the museum collection. Such solutions form the semantic layer of smart museum environment. This paper introduces our a) system design models for agent-based programming of museum information services, b) ranking models for semantic data mining in historical and cultural heritage domain. Our software implementation demonstrates the feasibility of the proposed models in respect to the user mobility, service personalization, and collaborative work opportunity.**

I. Introduction

A traditional museum has a database or a museum information system (MIS), which serves as an electronic archive or catalogue [1], [2]. Typically, museum personnel are the only MIS users. Visitors cannot access the MIS directly or their access functions are limited (simple browsing in some collected information). Nowadays, Internet of Things (IoT) drastically changes this traditional way of visitors activity in museum environments [3]. The IoT technology provides a lot of enablers that can be effectively used for making digital museums environments smart or intelligent. In particular, the IoT technology enables integration of MIS with visitors activity, hence opening many possibilities to engage the museum visitors with exhibits and available descriptive information. In general IoT, this approach follows Edge-centric Computing [4], when many edge devices are involved as surrounding computational participants into the service construction.

Museum exhibits are transformed to IoT objects providing information about themselves or even directly interacting with the users and other surrounding or remote objects [5]. Using sensors any object can be wrapped in its context and juxtaposed into it. The sensors observe the environment, analyze the situation, and provide support to the people enjoyment process. Multiple connections among the end-users are established through which they study and interpret information, stories, and multimedia content.

We follow the smart museum concept proposed in our previous work [6], [7]. Museum information services with high intelligence level can be constructed when additional historical sources are used to semantically enrich the museum collection, including knowledge acquired from visitors and museum professionals. Service construction is implemented on the semantic layer. A particular case is the History Museum of PetrSU in respect to everyday life history. The semantic layer enhances the existing MIS operating with digital representations of collected exhibits, descriptions of history-valued objects and facts as well as with any available fragments of historical knowledge.

In this paper, we continue our research and development of the semantically enriched collection on everyday life history in the History Museum of Petrozavodsk State University. We further study how the Semantic Web concept, the IoT technologies, and the smart spaces paradigm can be applied to solve the two important problem for creating a digital service-oriented environment for museum visitors and personnel: 1) offering personal recommendations on the museum collection with the use of semantic ranking methods and in context of the user and exhibition, 2) collaborative addition of information sources and their semantic annotation within the museum collection. In a result, this paper contribution is a) system design models for agent-based programming of museum information services, b) ranking models for semantic data mining in historical and cultural heritage domain. Our pilot software implementation demonstrates the feasibility of the proposed models in respect to the user mobility, service personalization, and collaborative work opportunity.

The remainder of this paper is organized as follows. Section II overviews recent advances in museum digitalization and defines the generic problems of smart museum environment. Section III considers the semantic layer-based smart museum environment. Section IV presents the semantic ranking methods with the use of ontological models for offering personal recommendations to museum visitors. Section V considers the problem of collaborative addition of sources and their semantic annotation. Finally, Section VI concludes the paper.

II. Problem statement

Recent progress in IoT technology, including advances in embedded, multimedia, and mobile devices, leads to many proposals for museum digitalization when operation with exhibits and related historical and cultural heritage information is made easier and more effective [3]. There have been many solutions focused on making visitor's mobile device (such as smartphones) a personalized access tool for service assistance in museum environments [8], [9], [10]. Nevertheless, these solutions do not consider the following generic problems of smart museum environment as a single set.

Offering personal recommendations with the use of semantic ranking methods: The offer of personalized recommendations to museum visitors is an important problem inherent to smart museum environments. Recommended services can solve this problem based on visitor preferences, as well as knowledge about the museum environment according to visitor profiles and context situation. It is important to note that recommendations can be based on some of personalized information delivered and collected as part of the interaction with the mobile device (e.g., history of viewing exhibits, exhibits ratings from visitors). Eventually, proper recommendation techniques lead visitors towards a museum artifacts of possible interest to facilitate and make more productive the visit. In this case, semantic ranking can be applied to reflect the semantic connectivity of a museum artifact with each another.

The basic idea of the recommendation techniques behind the Talking museum project [11] is that when a visitor is watching one a museum artifacts the system is able to: capture this event; select a set of candidate objects that are similar to the current ones, rank the candidate objects; arranges such objects in apposite visiting paths. The Talking museum project use as recommendation strategy a ranking method that strongly resembles the PageRank ranking system. In [12], the authors considered the recommendation service architecture, that is based on a multi-agent approach. Software agents retrieve data from available sources, create a semantic network around a definite point of interest, and provide recommendations for visiting other POIs that are interconnected with the initial point of interest. Such lightweight tool as Semantic Wiki is used to create a semantic network for the recommendation services. There have been many existing works on personalized recommendation for smart museum environment, where Semantic Web technologies and ontology-based modeling are used [13], [14]. For recommender systems based on semantic ranking algorithms Web 2.0 offers a rich semantic network with a large number of user communities and user generated content.

Collaborative addition of sources and their semantic annotation: Annotation is one of the most important problem in the domain of cultural heritage for providing useful information about surrounding entities, whether it is a museum artifacts, or a cultural attraction. In pervasive computing and IoT settings, this additional information can be used to digitally enrich the museum environment objects, which will help to improve visitors experiences and increase exhibit functionality. Visitors can interact with such objects, annotate them and share annotations with others. Moreover, additional information can contain (hidden) relations with other museum artifacts as well as with derived annotations about collected artifacts.

In [15], the authors proposed a theoretical conceptual model for the physical annotations systems, and defined the different types of annotated entities. The proposed model of physical annotation consists of the following parts: the annotation part, the physical entity, and the link between the annotation and the annotated entity. Furthermore, different possible relationships between annotations and annotated entities are considered. However, the obtained solutions are effective only for physical entities, and do not consider cases where the annotated objects are a virtual objects that are involved in the construction of virtual exhibitions in state-of-the-art museums [16]. Added annotations can be considered as digital object memory, when the object stores data about itself and links other objects [17]. For example, in the case of the museum environment, artifact memories can store information about the provenance of the artifact, about its history, and the flow of comments generated by visitors while interacting with the artifact. The proposed authoring system enables the writing, structuring, annotating and interlinking of the artifacts. However, the annotation process is independent of the other participants (non-collaborative): only the administrator can work with the system, using special tools for searching object information, editing the object memory, and adding optional materials about the object.

III. SMART MUSEUM ENVIRONMENT: SEMANTIC LAYER-BASED SOLUTION

The concept model of layer-based smart museum environment is shown in Fig. 1 (see also [6], [7]). The foundation of our vision of the smart museum environment is three classes of information sources, in addition to the basic collection of cultural heritage object descriptions in MIS: (a) expert historical knowledge available from museum personnel, (b)‘sources of individual (and possibly subjective) information available from museum visitors, and (c) Internet-enabled sources of historical information, e.g., such a service as DBpedia [18] and many existing web services.

A semantic network is created on top of the available knowledge corpus of descriptions collected from the above information sources. A semantic network is a directed graph consisting of nodes (vertices) representing domain objects and links (edges) representing semantic relations [6]. The nodes correspond to physical and digital exhibits, associated events, persons, and other objects. The links reflect interrelation of the objects.

The semantic layer is responsible to construct over this semantic network the following advanced services for smart museum: Visit service, Exhibition service, and Enrichment service. Solutions to the above generic problems of smart museum can be effectively supported based on the proposed semantic layer with these services.

Visit service: The service constructs a personalized exposition of recommended exhibits for a visitor to study. Such a recommendation is a small set of selected objects from the museum collection. This set is constructed from the available knowledge such that the set represents the most interesting facts for the visitor in her/his current situation. The service is responsible for construction of a visit program that can be personally recommended to a museum visitor. The service is also responsible for program adaptation during the visit depending on the preferences of the visitor and on the dynamically changing situation. The program is visualized on the public screen in the museum environment or on personal mobile devices of the users. Visit service operates with exhibit ranking: a non-negative rank value is associated with each exhibit to describe the recommendation degree (the higher rank the more recommendable).

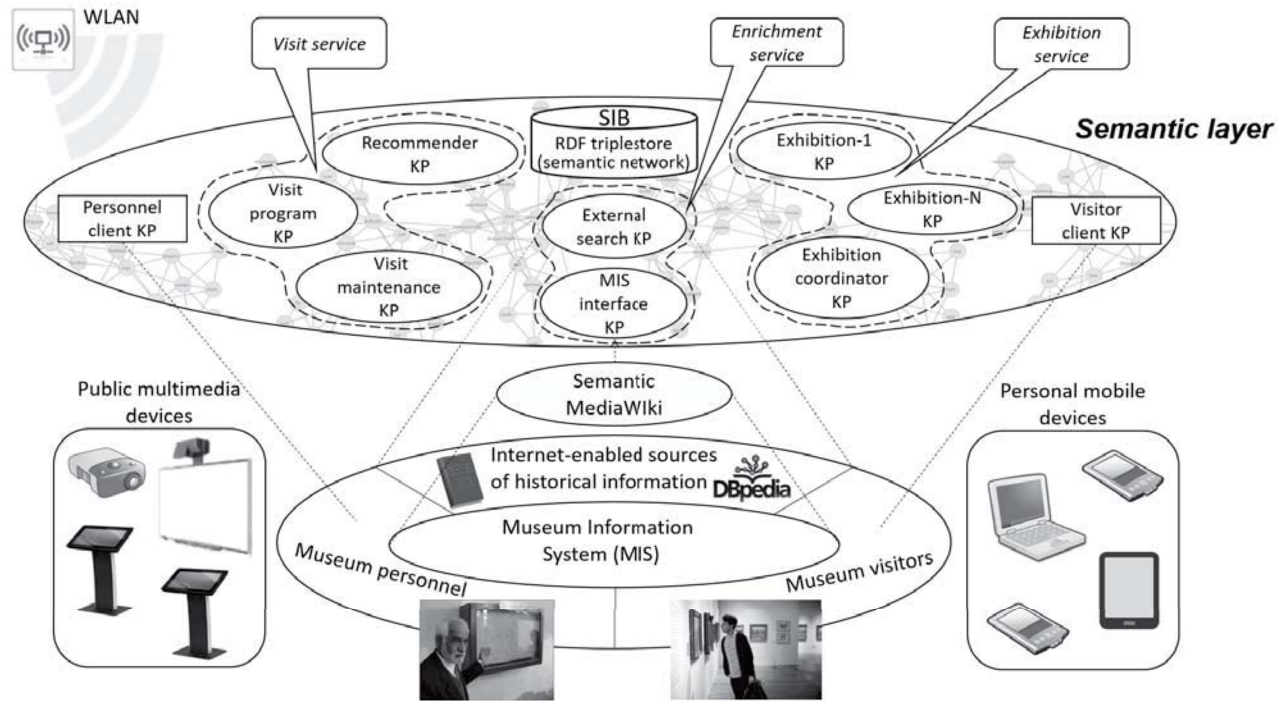


Fig. 1. Semantic layer-based smart museum environment

Exhibition service: The service shows selected descriptions and visual information about the studied exhibits on exhibition touch screens or even on personal mobile devices of the visitors. In fact, the service creates a kind of virtualization when a physical exhibition is augmented with digital representation. As in Visit service, Exhibition service acts as a recommender since the screens show the recommended (most interesting) facts derived from the available knowledge for the current context and situation.

Enrichment service: The service supports modification (evolution) of the semantic network by museum personnel and visitors. In fact, a museum visitor can enrich descriptions of studied exhibits, e.g., in the form of adding annotations. In the smart museum environment, a personal mobile device (e.g., smartphone running the mobile visitor client) becomes a primary access tool for this service. Adding annotations is useful in several scenarios. Firstly, the visitor adds missing descriptions and facts about an object. Secondly, if the visitor knows a history-valued relation of objects then she/he adds the relation (together with its description). Museum personnel can verify the correctness and value of this new information.

Our smart space-based design realizes the semantic layer in the smart museum environment as a multi-agent service-oriented information system deployed on the top of MIS [7]. The software infrastructure of system supports construction and delivery of the above services based on the semantic network. In accordance with the M3 architecture and Smart-M3 platform [19], [20], software infrastructure consists of the semantic information broker (SIB) and knowledge processors (KPs). SIB maintains the RDF-based knowledge base on top of MIS and other information sources. In particular, this knowledge base keeps the semantic network of museum exhibits and related information. KPs are software agents that are responsible for service construction and delivery.

Smart museum environment is characterized with specific digital devices, on top of which the software infrastructure creates an IoT-enabled service-oriented information system for human assistance and support. Public multimedia devices include interactive screen, media projector, and exhibition touch screens; the devices are primarily for service delivery by visualized provision of the information to the visitors. Personal mobile devices include smartphones, tablets, and laptops carried individually by the visitors and museum personnel; the devices can be used for personalized service delivery and participation in the activity. The local area network is created in the smart museum environment so that other participating devices can communicate locally as well as have access to external resources.

Each of the above services is implemented as a smart space service [21], [20], i.e., a service is considered as knowledge reasoning over the shared information corpus and delivering the result to the users and using the multi-agent approach. In our case, a service is a result of interaction of several KPs, which reactively or proactively cooperate over the shared information. Visit service is implemented by interacting the following KPs: Visit program KP, Recommender KP, and Visit maintenance KP. Enrichment service, in turn, is implemented by interacting the following KPs: External search KP and MIS interface KP. Exhibition service is implemented by interacting the following KPs: set of Exhibition-n KPs and Exhibition coordinator KP. A service is delivered to other services or users (via their client KPs).

Museum personnel and visitors can directly access the multi-agent system and consume services using specialized clients: Personnel client and Visitor client, respectively. These clients are separate client KPs that run on personal mobile devices. The clients provide access and control tool for the semantic network and for service construction. Visitor client supports watching the list of exhibits with their description, to record audio (video) with the comment to the exhibit, and to add text comment. Personnel client supports choosing exhibits for the exposition, adding new exhibits, and moderating reviews and other information coming from the visitors. In addition, personnel can control the current visualization on surrounding screens. Museum personnel and visitors can receive information and operate with services in any time and in other places, in addition to the smart museum environment, due to ubiquitous accessibility of the smart museum.

The ontological model is used for effective service construction. The model describes shared information, including available descriptions of museum exhibits and facts of everyday life history. The model provides structural rules for creating the required semantic network in the RDF triplestore (maintained by the SIB). The connection structure of the semantic network is the base for the required algorithms of information search, exhibits and descriptions ranking, and reasoning for discovery of complex semantic relations. The ontology covers the major museum exhibition aspects: exhibits and other historical objects, their descriptions and semantic relations. The ontology is based on CIDOC CRM [22], which is extended with a unique part for visit programs, exposition study, visitors, their interests, and recommendations.

IV. INFORMATION RANKING AND SEMANTIC MATCHING

Visit service offer of personalized information to museum visitors based on visitor preferences, as well as knowledge of the museum environment. Visit service includes Recommender KP, which calculates a rank value of exhibits. A class Rank provided in the ontological model for storing the ranks of the exhibits. The class Exhibit is always a rank object. A rank subject can be both the class Exhibit and the class Profile. The class Rank has three property: a rank value, a rank create time and a rank life time. The fragment of the ontology containing these classes is show in Fig. 2.

The semantic ranking methods use various algorithms to calculate the rank of a exhibits. The potentially adopts various ranking methods were presented in previous works about semantic network relations in [23]. Computational method in [24] solves the problem of ranking the available objects by the level of proximity to the visitor context based on the information about the set of the categories relating to a objects. Algorithms from recommender systems is divided into content-based, which are based on similarity of objects characteristics, and collaborative filtering, which are based on similarity of user preferences. Recommendations can be based on some of personalized information delivered and collected as part of the interaction with the mobile device (e.g., history of viewing exhibits, exhibits ratings from visitors). A context-aware recommender system from [25] ranks objects in terms depending on the similarity to user preferences. Since the semantic network provides rich structural information, we can use the methods of structural ranking. For instance, a variant

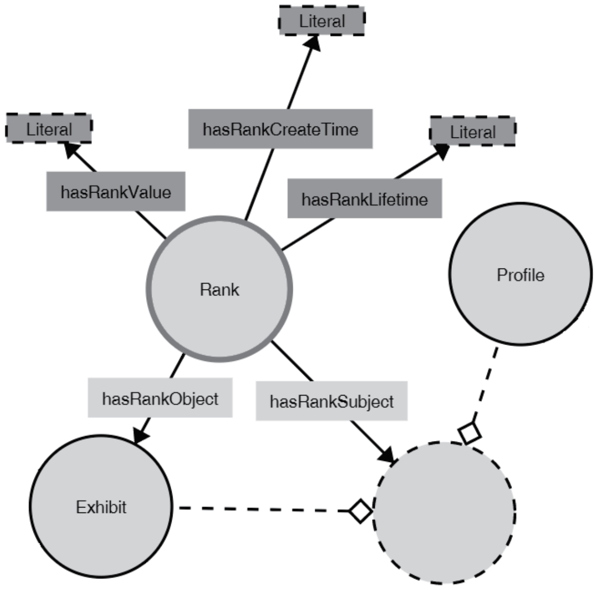


Fig. 2. Rank ontology: representation and linking with other concepts

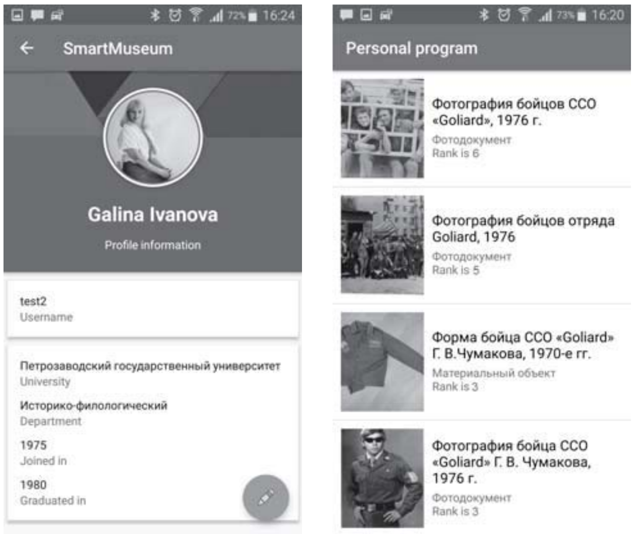
of the well-known PageRank algorithm [26]. The semantic matching method identifies information which is semantically related. We consider the following three types of ranking.

Firstly, the Recommender KP calculates rank for each exhibit based on the user profile. The rank of the exhibit directly depends on the user profile: the more the similarity of the description of an exhibit to the user profile, the higher an exhibit rank is.. As a result, for a specific user forms a list of ranks of exhibits. Such ranging is used from Visit service for construction of the personal program. Visit service needs to find a small group of tightly interrelated exhibits to form a given thematic exposition. Exhibits in this thematic exposition are ranked according to the user profile. Visit service provides the opportunity to present personal program, associated information. where exhibits are semantically matched with the user.

Secondly, the rank calculates for each exhibit relatively to other exhibits. This semantic ranking applied that reflects the semantic connectivity of any museum artifact with each another. The more coincidence of properties from the exhibits is, the higher the rank between them. Such ranging is used from Exhibition service when a visitor views the current exhibits. Exhibition service can visualize descriptions of the recommended exhibits on the surrounding screens or on the personal mobile device when a visitor comes to the exhibit and studies associated information.

Thirdly, iterative ranking of objects, which is relative to a specific exhibit and user, is done in a situation where the user views a particular exhibit. At first, there is a search of relatives to particular exhibits (1). Then these exhibits are ranked according to the user profile (2). As a result the user sees the list of exhibits similar on current and most interesting to himself. Exhibition service performs additional ranking to recommended exhibits associated with the user.

Now let us consider an use case of constructing of the personal program for the particular user profile. At the moment the user profile contains a little information. First of all



Profile details Personal program

Fig. 3. Personal program for a particular user profile

user profile contains information about education and student community, because our services knowledge base focus on the history of Petrozavodsk State University and everyday life history. We plan to expand the profile with other information. Screenshots from a mobile device is shown in Fig. 3. In this use, case user profile contains the following data:

1) the first name: Galina
2) the second name: Ivanova
3) the university where the user studied: Petrozavodsk State University
4) the department where the user studied: the Department of History and Philology
5) the user joined to university in: 1975
6) the user graduated from university in: 1985
7) important places for the user during studying: Petrozavodsk, Medvezhyegorsk, Padanyi.

Semantic matching was conducted between user data and exhibits information. The table shows the matching data of the most relevant exhibits. The more the similarity of exhibit information to the user profile, the higher an exhibit rank is. Semantic matching between profile and exhibits performs according to ontological model described in [7], [5].

Relevant exhibits are more than depicted in the Fig. 3 in Personal program, but we review in detail only the first four. As can be seen in Fig. 4 all relevant exhibits refer to the Department of History and Philology, where Galina Ivanova studied. These exhibits are dated 1976, refer to the period of study. Exhibits have a relationship to a specific persons. Graduates of different years can be interested in photo show of their fellow students. If the period of study at the university of these persons and the department match with specified in a profile, then the semantic matching also is counted. Thus, the rank of the exhibit is the sum of matches between user profile and exhibits information. Exhibits are sorted descending of a rank and displayed on the user mobile device.

№	exhibit	semantic matching with the user profile	rank
1	Photo of members of the student construction brigades «Goliard» 	– date **1976** – refer to department **the Department of History and Philology** – has been made in place **Padanyi** – represents possible friends: 1) S. Verigin (has Person Education: **1973-1978 the Department of History and Philology in PetrSU**) 2) T. Yuldashev (has Person Education: **1973-1978 the Department of History and Philology in PetrSU**) 3) V. Efimov (has Person Education: **1974-1979 the Department of History and Philology in PetrSU**)	6
2	Photo of members of the student construction brigades «Goliard» 	– date **1976** – refer to department **the Department of History and Philology** – has been made in place **Padanyi** – represents possible friends: 1) V.Birin (has PersonEducation: **1974-1979 the Department of History and Philology in PetrSU**) 2) N. Pochtovalov (has Person Education: **1974-1979 the Department of History and Philology in PetrSU**)	5
3	Uniform of G. Chumakov 	– date **1976** – refer to department **the Department of History and Philology** – owner is a possible friend: G. Chumakov (has Person Education: **1973-1978 the Department of History and Philology in PetrSU**)	3
4	Photo of G. Chumakov 	– date **1976** – refer to department **the Department of History and Philology** – represents a possible friend: G. Chumakov (has Person Education: **1973-1978 the Department of History and Philology in PetrSU**)	3

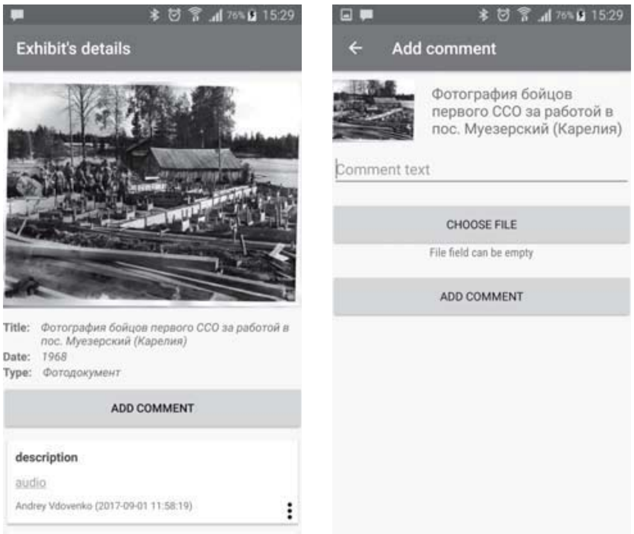
Fig. 4. Semantic matching of user data and exhibits information

V. COLLECTIVE ANNOTATION

Users of system have feature for adding annotations to specified exhibit. Exhibit annotation helps to enrich data sources with a new information. This information can lead to producing new knowledges, like relations between exhibits or persons, that was not possible to discover without this pieces of data. At same time, annotations consist of bunch of meaningless information for analyzing and this lead to a task of selecting small significant labels of annotations, e.g. words and sentences, and analyzing them by system and personnel.

Exhibit annotation can be of different types such as audio or video records, pictures, and plain text. Semantic annotation on data source of different type have become very important direction in Semantic Web [27], [28]. Data sources can be mapped to ontology concepts for capturing meaning of integrated elements. This raise problem on parsing data source and producing more compact and efficient representation of it. In this field there is a lot of results that can be used for our purposes [29], [30]. Our goal is help to personnel on first phase of analyzing by initial semantic analyzing of annotations received by participants and other personnel.

As sources for semantic annotation are participants and personnel of museum. A participant could be involved in life of university and has some additional information to add, e.g.



Exhibit's details Add comment

Fig. 5. Participants add comments on an exhibit

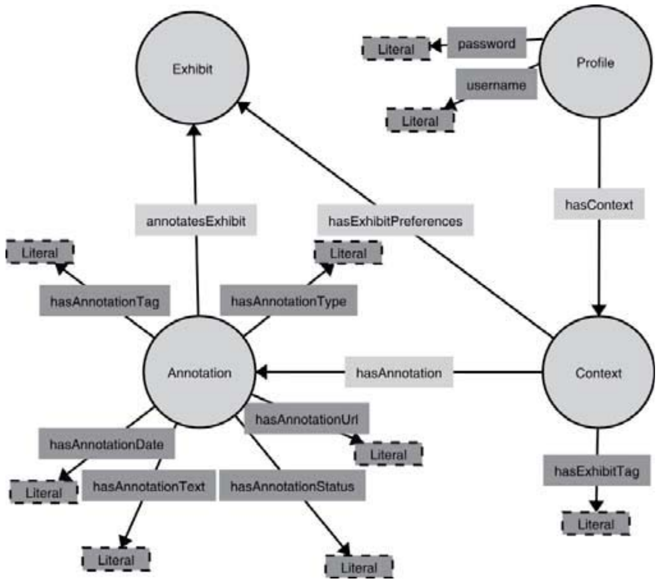


Fig. 6. Annotation ontology: representation and linking to other concepts

he knows persons on the picture or when picture was taken. This information are accessible by other participants and can have an impact on producing another one. Second variant of enrichment is more traditional, when some person brings an exhibit to the museum and a personnel enter information about it into the system.

Participants use mobile client to add information to specified exhibit, see Fig. 5. This information added as comments with attachment. On post event client forms HTTP request from comment, that sent to a content service. Content service receives request, determines type of uploaded file, stores it, and posts comment information in smart space and connects it with creator person and related exhibit through appropriate properties. Such comments are assigned with status of moderation.

Personnel take role of moderator and translator of user comments to new exhibits on Semantic MediaWiki. Personnel receive notification on new comments in system through personnel client represented by web application. Personnel check semantic annotation of comment, its appropriateness to specified exhibit and also can add extra tags. After that comment is marked with accept status, other users can see it on the mobile clients. They also can add comments to it with pointing on some conflicts in facts, that can help to personnel resolve controversial situations.

Semantic annotation are based on determining occurrence of key words that match some predefined patterns and setting appropriate tags. Patterns can be as names of faculties or significant persons, geographical locations, dates and etc. In case of media content, we use pattern recognition technologies to parse them to plain text for next analyzing. A patterns set is filled by personnel during of the system work. Personnel check comment tags before publishing for participants and after their feedback. Participants also can check given tags and add some missed or mark one as incorrect.

An ontology representation of annotations is shown in Fig. 6. Annotation individual connected with participant Profile through Context entity. Context property is helpful for determining area of interests and building personalized program in advance. Annotation stores typical information about publish date, url and type of file and list of tags. Also annotation relates with Exhibit entity, for understanding which exhibit is annotated and forming annotations list in mobile client.

Semantic annotations of participants comments are used as additional data source by personnel to produce new exhibits and to set relations between already exist entities. Also group of annotations can be connected in semantic network and provide ability to perform complex searching, e.g. relations between two persons.

VI. Conclusion

This paper reported the progress in the development of a smart museum of everyday life history within the History Museum of Petrozavodsk State University. Science-intensive solutions to the two applied problems are considered for the domain of historical knowledge and cultural heritage: 1) offering personal recommendations with the use of semantic ranking methods, 2) collaborative addition of information sources and their semantic annotation. Our pilot implementation show the effective use of Semantic Web, Internet of Things, and smart spaces technologies for implementing the semantic layer in this class of digital service-oriented environments. The users of smart museum services—museum visitors and personnel—are supported with such effective properties as the user mobility, service personalization, and collaborative work opportunity.

Acknowledgment

The reported software development is financially supported from Department for Humanities of Russian Fund for Basic Research according to project # 16-01-12033. The research study is supported by the Ministry of Education and Science of Russia within project # 2.5124.2017 of the basic part of state research assignment for 2017–2019. The work is implemented within the Government Program of Flagship University Development for Petrozavodsk State University in 2017–2021.

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